XIII. STRUCTURE OF THE FORE LIMB AND MANUS OF BRONTOSAURUS.

By J. B. Hatcher.

Notwithstanding the abundance of the remains of the Sauropod Dinosaurs in the Jurassic deposits of the West and the exceptional vigor with which the collecting of these remains has been carried on, in the earlier days by the late Professors Marsh and Cope and more recently by Osborn, Williston, and the Carnegie and Field Columbian Museums, much still remains to be learned concerning the complete osteology of even the commoner genera and species. By the combined efforts of all engaged in the collecting and studying of Dinosaur remains, rapid and substantial progress is being made in our knowledge of the structure of these gigantic reptiles which in size equalled or surpassed that of any other known animals either living or extinct. The facts set forth in the present paper concerning the structure of the manus of Brontosaurus, which most likely does not differ materially from that of the same element in the other genera of the Sauropoda, affords a striking illustration of the proximity with which one discovery follows another, shedding new light on doubtful points and making it for the first time possible to substitute facts for conjecture concerning the structure of previously unknown characters. Hardly had the Memoir on Diplodocus,[1] prepared by the present author and based upon much the best material pertaining to that genus yet discovered, been received from the press, than a second skeleton, belonging to a distinct but closely allied genus, *Brontosaurus*, was received at the Museum. This contained, beside many other parts of the skeleton, a nearly complete fore limb and foot, elements entirely wanting in our skeleton of Diplodocus. This fortunate discovery calls for an entire revision of the structure of the manus of Brontosaurus at least, as that element has been reconstructed, figured and described in recent publications by Prof. H. F. Osborn,[2] while at the same time making it extremely probable that the manus of both Morosaurus

[1] Memoirs of the Carnegie Museum, Vol. I., No. 1.

[2] Bull. Am. Mus. Nat. Hist., Vol. XII., pp. 161–172, and Vol. XIV., pp. 199–208.

and Diplodocus has been erroneously constructed both in Osborn's figures and in my own restoration of the skeleton of the latter genus, where, as stated in the text, I followed that author when reconstructing the anterior limbs and feet, parts of the skeleton not represented in our collections.

Discovery of the Skeleton of Brontosaurus (No. 563).

The skeleton with which the limb and foot under discussion belonged was discovered by Mr. Charles W. Gilmore, a graduate of the University of Wyoming and member of the staff of the Section of Vertebrate Paleontology of this Museum. It was found in the shales of the Atlantosaurus beds, about one mile south of Sheep Creek in Albany County, Wyoming. The particular locality (Quarry E) at which the skeleton was dug up was distant about one quarter mile from Quarry D, which had yielded the two skeletons of *Diplodocus carnegii* (Nos. 84 and 94) belonging to this Museum's collections. While both quarries are in the same bed of shale, Quarry E is in a distinctly lower horizon than Quarry D. Careful measurements taking into consideration the dip of the strata would probably place the horizon of Quarry D from 30 to 40 feet above that of Quarry E.

The different parts of the skeleton recovered were for the most part disarticulated when found. But when, as with the present limb and foot, any bones were found in nearly or quite their normal positions, such portions were taken up and packed by Mr. Gilmore with such precaution and skill that they have been received in the laboratory oi the Museum in the same positions in which they were found and still partially imbedded in the original matrix. Moreover, in order that no possible aid should be lost which a knowledge of the various positions of the different bones when found in the quarry might furnish in assigning each to its proper position in the skeleton after their arrival in the Museum, Mr. Gilmore prepared an excellent diagram of the quarry and carefully located on this each bone as it was uncovered during the process of excavation, thus securing a permanent and reliable record of the relative positions of the different parts of the skeleton as they lay imbedded in the rock.

Relative Positions of the Humerus, Radius, Ulna and Manus in the Matrix.

When found the forearm and manus lay with the palmar side up. The humerus was not in position at the proximal end of the radius and ulna, but lay with its dorsal side up, the middle of the shaft resting on the proximal end of the ulna with its longer axis at right angles to that of the radius and ulna.[1] The proximal end of the radius lay in the radial groove on the anterior surface of the ulna. Lying between and upon the palmar side, near the distal ends of the radius and ulna, was a large flat bone, the scapho-lunar, presenting on one side a gently but regularly convex surface and on the other two flat, subequal surfaces separated by a low ridge.

Metacarpals I., II., III., IV., and V. were in regular order at the distal extremity of the radius and ulna. The proximal ends of metacarpals I. and V. were closely applied to the external lateral surfaces of the distal ends of the radius and ulna, indicating that in life they articulated directly with these bones perhaps through the intermedium of heavy cartilaginous pads, while the three median metacarpals were still interlocked at their proximal ends, as shown in plate XX., and a little more removed from the distal ends of the radius and ulna, as though to accommodate the supposed scapho-lunar mentioned above.

The proximal phalanges of all the digits were present and nearly in their normal position with relation to their respective metacarpals. That of digit I. was in contact with its metacarpal but shifted from its normal position so that its external lateral surface was opposed to the distal end of the metacarpal, with its proximal articular surface turned inward toward the median axis of the foot and the distal outward. The proximal phalanx of digit II. was in position at the extremity of metacarpal II., but very much flexed, so that its longitudinal axis stood almost at right angles to that of metacarpal II. The first phalanx of digit III. was found in its proper position at the extremity of metacarpal III. and there was on the palmar side, interposed between it and that bone, a small rounded sesamoid. The proximal phalanx of the fourth digit was in position articulated with metacarpal IV. That of digit V. lay at the extremity of its metacarpal, but with its external lateral surface opposed to the distal end of the latter. These were the only phalanges found with this foot except the ungual of the first digit, which lay in its normal position with reference to that of the first phalanx as the position of the latter has been described above, except that it was turned on its side and had been moved

[1] In a preliminary note in *Science* I stated that the humerus was in position at the proximal end of the radius and ulna, having misunderstood Mr. Gilmore in reference to this particular. See *Science*, Vol. XIV., No. 365, p. 1015.

slightly backward and lay with its articular surface abutted against the external border of the distal articular surface of the first phalanx and the external lateral surface of metacarpal I.

There was a slight vertical displacement in the carpal region so that the distal ends of the radius and ulna were a little lower than the metacarpals. Metacarpals I. and V. lay in such position with reference to II., III. and IV. as to indicate that the proximal ends of these bones were arranged in the arc of a circle and not horizontally.

Preparation of the Fore Limb and Manus in the Laboratory.

The same painstaking care given by Mr. Gilmore to the work in the field has been exercised in the laboratory in the preparation of the limb, manus, and other portions of the skeleton for study and exhibition purposes.

The entire limb and foot were taken up in two blocks. One of these contained the humerus while in the other were imbedded the radius, ulna and manus. These were packed in separate boxes and forwarded to the Museum along with the remaining portions of the skeleton and other material collected during the season by Mr. Gilmore's party, amounting in all to some fifty large cases.

When unpacked in the laboratory the block containing the radius, ulna, and manus, as also that containing the humerus, were in a perfect state of preservation, having sustained no injury while being transported from the Wyoming quarry to the Museum in Pittsburg. These blocks were each placed on an operating table resting on the side which had been lowermost as they lay in the quarry. That containing the forearm and manus was assigned to Mr. Gilmore for preparation, while Mr. Louis Coggeshall prepared the humerus. The strips of burlap, which had been saturated with paste, or cement and plaster, and wound about the blocks in such manner as to form a perfect casing, binding together the entire mass and holding even the most minute fragment in its original position, were carefully cut away from the superior surface, exposing the entire palmar surfaces of the radius, ulna, and bones of the manus. The upper surface of these bones was then thoroughly cleaned and the matrix removed from between and about them, without disturbing in any way their original positions, until each stood out in high relief. Next the photograph reproduced in plate XIX. was taken and a plaster bed then made over all in order to preserve an impression of the bones as they lay still slightly fixed in the original matrix. After this bed had hardened sufficiently it was removed and the different bones were taken up and thoroughly cleaned and fitted in their proper positions as indicated by the respective depressions made by each on the surface of the plaster bed. When all had been thus cleaned and replaced the photograph reproduced in plate XX. was taken, showing the relative position of the different elements from the dorsal or lower side of the fore-arm and manus as they lay imbedded in the shale. In this manner we have preserved the complete record of this limb and foot from the time of its discovery until its final preparation in the laboratory. No single fact has been lost which would aid us in a correct interpretation of the structure and arrangement of the different elements in the fore-limb and manus of this particular type of dinosaur. To some the careful methods thus detailed may appear as superfluous, but I am convinced that they are not only desirable, but absolutely necessary, if we are ever to arrive at an exact and satisfactory understanding of the skeletal structures in the Dinosauria, where articular surfaces are in most cases so poorly defined as to afford little evidence concerning the exact position of bones found isolated, or detached and misplaced through careless or indifferent field and laboratory methods. It is impossible to attach too much importance or give too great credit to Mr. Gilmore for the appreciation, judgment, and skill shown in collecting and packing this skeleton, while the ingenuity of Mr. A. S. Coggeshall in devising and improving laboratory methods, whereby these heavy and exceedingly fragile bones are readily cleaned and hardened so as to permit of being safely handled, is deserving of the greatest praise.

DESCRIPTION OF THE LIMB.

The Humerus.—The shaft of this bone is much constricted, while the extremities are greatly expanded transversely, the proximal to a much greater extent than the distal. There is a very prominent deltoid ridge extending along the anterior external border from the proximal end throughout one-half the length of the bone. Between the ridge and the inner margin there is on the anterior surface a rather deep basin, subtriangular in outline, bounded above by the anterior border of the slightly thickened broad proximal end, and externally and internally by the deltoid ridge and internal lateral margins, which converge inferiorly where the shaft becomes much restricted. The proximal end has the transverse diameter much expanded while the fore and aft is quite short. In the present specimen the differences between these two diameters is somewhat magnified through distortion due to crushing. Superiorly the proximal end is regularly convex, so

FIG. 1. Anterior view of right humerus, about one tenth natural size. (No. 563.)

that when seen from behind or in fiont its upper border describes an almost perfect arc, the chord of which in the present specimen has a length of 600 mm. (23⅝ inches). The head is placed about midway between the external and internal borders, but a little nearer to the latter, and is directed rather strongly backward much as in the testudinata. It is very rugose, only moderately expanded in either direction.

Distally the transverse diameter of the humerus is about double the fore and aft. The articular surface is exceedingly rugose and deeply pitted as though covered in life with heavy cartilaginous epiphyses

FIG. 2. Posterior view of right humerus, about one-tenth natural size. (No. 563.)

which never became thoroughly ossified and through the intermedium of which it articulated with the radius and ulna. On the posterior border there is an emargination indicative of an anconeal fossa. This is extended into the articular area in such manner as to cause a slight median constriction on the posterior side directly opposite a slight anterior expansion on the anterior surface. There is a small and imperfectly defined external condyle. The posterior border of the humerus is regularly convex transversely throughout most of its length, though much flattened proximally and slightly grooved distally. The principal characters are shown in Figs. 1, 2, 3, which present respectively the anterior, posterior, and distal views of this bone. The principal measurements are:

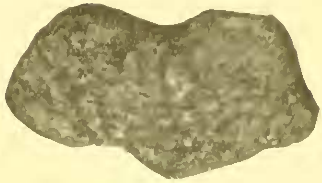

FIG. 3. Distal end of right humerus about one-tenth natural size. (No. 563.)

Greatest length,	1,100 mm.	43¼ in.
" transverse diameter at proximal end,	600 "	23⅝ "
" " " " distal "	410 "	16⅛ "
Transverse diameter at point of greatest constriction,	210 "	8¼ "

The Radius and Ulna.—These bones are subequal in size. The distal third of the ulna is a little more slender than the same portion of the radius as shown in plates XIX. and XX., and in Figs. 4, 5, 6, 7, 8, and 9. The shaft of the radius is constricted medially while the ends are about equally expanded. The proximal end is semi-circular in cross-section, the convex surface fitting nicely into the radial groove on the anterior surface of the proximal end of the ulna. Proximally the radius articulates only with the anterior and internal portion of the distal articular surface of the humerus, as is well shown in Figs. 4 and 6 and in plate XX. The proximal end of the ulna entirely encloses that of the radius posteriorly and externally so that its articular surface is opposed to that of the distal end of the humerus posteriorly throughout its entire breadth, while at the same time presenting a broad and deep articular surface on the anterior projection which encloses the radius externally for contact with that of the anterior and external surface of the humerus. The contact of the radius with the humerus is thus limited to the antero-internal surface of the humerus instead of the antero-external as determined by Osborn and Granger,[1] so that these bones are not so completely crossed as these authors had supposed, but occupy positions almost identical with those figured by the late Professor Marsh as obtaining in the fore limb of Morosaurus.[2] Seen from above the proximal end of the ulna may best be described

[1] See Bul. Am. Mus. Nat. Hist., Vol. XIV., pp. 199–208.

[2] See Part I. Sixteenth An. Report U. S. G. S., pp. 143–244, Plate XXXVII.

as tri-radiate. The rays are formed by the posterior anconeal spine, the directly opposite external anterior projection and the widely ex-

FIG. 4. Front view of right radius, ulna and manus in position about one-tenth natural size. (No. 563.)

panded internal portion. The first two of these are subequal and much smaller than the last. All are separated by concave surfaces. There is a deep cavity on the posterior surface between the anconeal spine and the internal, lateral margin of the ulna. Distally the radius shows a prominent rugosity on the posterior side near the externa border. This commences about four inches from the distal extremity and continues as a prominent narrow ridge for a distance of nine inches. At about one third the distance from the lower to the upper end of this rugosity it is interrupted by a deep groove which starts on the inner side, runs obliquely downward and outward, completely

FIG. 5. Distal ends of right radius and ulna in position, about one-tenth natural size. (No. 563.)

FIG. 6. Proximal end of right radius and ulna in position, about one-tenth natural size. (No. 563).

bisecting the rugosity. This groove doubtless served for the transmission of an artery. Opposed to this rugosity on the radius there is a similar one on the middle of the internal surface of the ulna near its distal extremity. These rugosities doubtless served for the attachment of the muscles which held these bones in place. Seen from below, the articular surface of the distal end of the radius has the form of an elongated ellipse with an area somewhat exceeding that of the distal end of the ulna, which takes the form of an oblique quadrangle with its two axes nearly equal. There is on the internal surface of the distal end of the ulna a rather deep emargination or fossa for the reception of the rounded postero-external angle of the distal end of the radius. This emargination appears, though less distinctly, on the internal border of the distal articular surface of the ulna, as shown in Fig. 5. Its presence affords great assistance in the proper adjustment of these bones, since when they are so placed that the convex surface of the proximal end of the radius fits nicely into the radial groove of the ulna and the postero-external angle of the distal end of the radius in this fossa there can be no question as to the correct relative positions of these bones. The articular surfaces of the distal ends

FIG. 7. Posterior view of right radius, about one-tenth natural size. (No. 563.)

of the radius and ulna display different degrees of rugosity. The postero internal portions of each are extremely rugose and deeply

FIG. 8. Posterior view of right ulna, about one-tenth natural size. (No. 563.)

FIG. 9. Anterior view of right ulna, about one-tenth natural size. (No. 563.)

pitted, while toward the center the surface becomes less indented and the external one half of each presents a polished surface marked with shallow corrugations.

PRINCIPAL DIMENSIONS OF RADIUS AND ULNA.

Greatest length of radius,	755	mm.	29⅝	in.
Transverse diameter of radius at distal end,	230	"	9⅛	"
Fore and aft " " " " " "	105	"	4 1/16	"
Transeverse " " " " proximal "	240	"	9⅜	"
Fore and aft " " " " " "	95	"	3⅝	"
Transverse " " " " middle of shaft,	127	"	5	"
Greatest length of ulna,	740	"	29⅛	"
Transverse diameter of ulna at distal end,	155	"	6	"
" " " " " proximal "	330	"	13	"
Fore and aft diameter at summit of anconeal spine,	205	"	8⅛	"

The Carpus.—There was but one carpal bone found with the present limb and foot, that marked X. in plate XIX. This agrees very closely with the description given by Osborn and Granger of the supposed scapho-lunar in Diplodocus, and with those authors I agree in making it homologous with that element in the mammalian carpus. If my interpretation of the position of this bone in the manus is correct the following description of this element would apply. The general form is that of a circular disc, thin in front but considerably thickened posteriorly. The superior surface is crossed antero-posteriorly by a low, broad ridge which divides it into two slightly concave and subequal surfaces, the larger and smoother of which was for articulation with the external half of the distal end of the radius, while the smaller and more rugose surface articulated with the internal portion of the distal articular surface of the ulna. Inferiorly this bone presents a gentle convex, polished, but corrugated surface for articulation with metacarpals II., III. and IV. No other carpals were found with or near this foot, and after a careful study of it and the articular surfaces of the distal ends of the radius and ulna and considering the position in which metacarpals II., III. and IV. lay with reference to these bones and metacarpals I., and V., as shown in plates XIX. and XX., it appears quite probable that it was the only ossified element present in the carpus of Brontosaurus and therefore that the Brontosaur carpus, like the tarsus, consisted of a single element. An oblique front view of this bone is shown in Fig. 10.

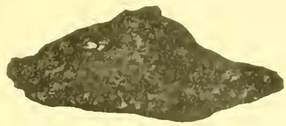

FIG. 10. Right scapho-lunar front view seen obliquely from above, about one-fourth natural size. (No. 563.)

PRINCIPAL DIMENSIONS.

Greatest transverse diameter	203 mm.	7⅞ in.
" fore and aft "	155 "	6⅛ "
" thickness	55 "	2⅛ "

The Metacarpals.—All the elements of the metacarpus were present and in approximately their normal positions when the foot was uncovered, as shown in plates XIX. and XX.

Metacarpal I. is short and much the strongest bone of the entire series. The proximal end is very deep, but much compressed. The articular surface is gently concave vertically and convex transversely. The internal lateral margin of the proximal end is regularly convex so that this margin and the proximal articular surface as well conform to the internal margin and internal articular surface of the radius with which during the life of the animal it probably had a direct, cartilaginous articulation. The external lateral margin of the proximal end is regularly concave and just in front of the articular surface there is a deep cavity for the reception of a corresponding prominence on

FIG. 11. Dorsal view of metacarpals of right manus placed side by side in regular order, about one-tenth natural size. (No. 563.)

the internal margin of metacarpal II. The external surface is rugose throughout the entire length of the bone; it is much constricted vertically in the middle, but with decided distal and proximal expansion for contact with metacarpal II. The internal lateral surface is regularly but gently convex vertically throughout the entire length of the bone and only slightly constricted vertically in the middle region. The superior surface gradually broadens from the proximal to the distal end. The inferior surface is deeply concave longitudinally, broad at the distal extremity, but reduced to a sharp narrow ridge at the proximal end. The distal articular surface has the vertical and transverse diameters subequal. It is continued well back on the palmar side of the bone in order to accommodate the thin sheet of bone which projects posteriorly from the palmar side of its proximal phalanx. There is a vertical, median groove for the accommodation of the low median keel of the latter.

Metacarpal II. is longer and more slender than the preceding, although decidedly stronger than metacarpal III. It is somewhat constricted medially both in its vertical and lateral diameters. Compared with metacarpal I. it is broad, but greatly depressed. The superior as well as the distal portions of the lateral surfaces are smooth, while the inferior and proximal portions of the lateral surfaces are covered with rugosities. The inferior internal angle of the proximal end of this bone is especially modified so as to fit nicely into the deep cavity just described as present on the external lateral surface of metacarpal

I. These bones are so interlocked that when placed in position a considerable portion of the proximal end of mc. II. is covered over by the superior border of the cavity in mc. I., while the proximal

FIG. 12. View of proximal extremities of metacarpals of right manus in position about one-fourth natural size. (No. 563.)

end of the latter is raised above that of mc. II. so as to articulate directly with the radius. There is a broad, shallow excavation on the external lateral surface at the proximal end of mc. II. for the reception of the internal proximal angle of mc. III. The proximal articular surface of mc. II. is broad above and somewhat narrowed inferiorly. Its superior and inferior margins are bounded by nearly straight, horizontal lines. The surface is very slightly and regularly convex in all directions. The distal articular surface is broad and deep, though in the present specimen the latter diameter has been somewhat diminished by pressure. Just anterior to the rugosity on the internal lateral surface of the proximal end of this bone there is a deep groove leading obliquely downward and forward to the palmar surface. This may have served for the transmission of a flexor tendon.

Metacarpal III. is of equal length, but decidedly more slender than mc. II. The superior surface is smooth and regularly convex. There is a noticeable lateral constriction at about the middle of the distal one-half of the bone. On the internal lateral surface of the proximal end there is a flat rugose area, broad proximally, but narrowed distally, which disappears toward the middle of the shaft. The internal, proximal, lateral angle is so shaped as to fit nicely into the cavity on the external lateral surface of the proximal end of mc. II., causing an interlocking of the proximal ends of these bones. The proximal articular surface is subtriangular in outline through the external superior lateral angle of the proximal end being produced into a strong triangular process which overlies a corresponding projection on the internal inferior lateral angle of mc. IV. The external outer margin of this process on mc. III. presents a rounded articular surface which fits into a deep groove on the superior internal surface of mc. IV., thus causing these bones to interlock at their proximal ends, though somewhat less perfectly than mcs. I. and II., and II. and III. The palmar surface of mc. III. is rugose and there is a broad median ridge continued throughout the entire length of the bone. The distal end is broad and deep, convex, and with an indistinct groove inferiorly.

Metacarpal IV. is shorter and more slender than mc. III. It is greatly constricted medially and at the point of greatest constriction it is nearly circular in cross-section instead of flat as in mcs. II. and III. On the internal lateral surface of the proximal end there is the deep groove mentioned above for the accommodation of a corresponding prominence on the external lateral surface of mc. III. The proximal articular surface is triangular. The lines bounding the internal and superior borders are of equal length and meet at right angles so as to form the base and perpendicular of a right-angled triangle, while the hypotenuse is formed by the line bounding the external lateral border. The latter, when this bone is placed in its natural position, runs obliquely downward and inward toward the median axis of the foot. There is a broad, shallow emargination on the external lateral surface near the proximal end. The distal end presents a broad and deep articular surface concave transversely and convex supero-inferiorly.

Metacarpal V. is shorter and stronger than mc. IV. It has something of the general shape of mc. I., though not nearly so massive as that bone. It is compressed proximally, but expands distally. There is a broad, rugose, concave surface on the internal side of the proximal end. The proximal articular surface is crescentic in outline with the upper arm heavier than the lower. There is a deep constriction on the inferior side and another less pronounced on the superior just behind the distal end. The distal articular surface is faintly convex and subcircular in outline.

The manner in which the different elements of the metacarpus interlock at their proximal ends is suggestive of that which obtains in the mammalia and is well calculated to give stability to the manus when supporting the weight of the ponderous body. It will also, now that the position of each is definitely known, furnish important aid in assigning the various metacarpals when found disassociated to their proper positions. Some of the principal characters of the metacarpals are well shown in plates XIX. and XX. and figs. 4, 11, and 12.

Principal measurements of metacarpals, column 1, greatest length; 2, greatest transverse diameter at proximal end; 3, greatest transverse diameter at distal end; 4, least transverse diameter of shaft.

	1.		2.		3.		4.	
	mm.	in.	mm.	in.	mm.	in.	mm.	in.
Mc. I.	257	10⅛	80	3⅛	103	4	70	2¾
Mc. II.	285	11¼	122	4¾	149	5½	80	3⅛
Mc. III.	285	11¼	110	4½	119	4⅝	70	2¾
Mc. IV.	240	9½	76	3	110	4¼	60	2⅜
Mc. V.	232	9⅛	68	2⅝	110	4¼	57	2¼

Depth of Mc. I. at proximal end,	155 mm.	5⅝ in.
" " " II. " " "	85 "	3¼ "
" " " III. " " "	74 "	2⅞ "
" " " IV, " " "	125 "	4⅞ "
" " " V. " " "	142 "	5½ "

The Phalanges.—The entire series of proximal phalanges are present as is also the second or terminal phalanx of the first digit.

The proximal phalanx of the first digit is longer on the external than on the internal side, so that when in position between the ungual and Mc. I. it appears wedge shaped, with the wedge directed toward the opposite foot. The internal lateral surface is convex and the external deeply concave. The palmar surface is produced posteriorly into a thin sheet which lies under the distal end of mc. I. The proximal articular surface is concave supero-inferiorly and there is a low, broad keel for articulation with the groove in the distal articular surface of mc. I. The distal articular surface is regularly convex supero-inferiorly and concave transversely.

The ungual of the first digit is compressed laterally but deep posteriorly. The internal lateral surface is convex, the external flat. The proximal articular surface has been so much distorted by pressure, due to the position in which it lay when imbedded, that its characters are obscured in the present specimen. The distal extremity is pointed and the entire external surface throughout the distal two-thirds of its length bears evidence of its having borne a powerful claw during the life of the individual.

The proximal phalanx of the second digit is much the largest of the entire series. The proximal articular surface is flat and circular in outline, the vertical and lateral diameter of this end of the bone being equal. Distally this phalanx is much depressed and greatly expanded transversely. The distal articular surface is very broad but shallow and divided by a deep, median, vertical groove into two subequal lateral moieties with smooth convexly rounded surfaces. This phalanx, as well as its metacarpal, has been erroneously considered as belonging to the third instead of second digit of the series by Professor Osborn, as will readily appear by a reference to fig. 7 of that author's paper on the "Fore and Hind Limbs of Carnivorous and Herbivorous Dinosaurs," published as Article XI. of Vol. XII. of the Bulletins of the American Museum of Natural History.

The proximal phalanx of the third digit is short, very much depressed, more especially at the distal end, and expanded laterally. The proximal articular surface is elliptical in outline, slightly concave, with its transverse diameter about double that of the vertical. The distal articular surface is broad, but extremely shallow. There is a broad but very shallow depression in the middle, faintly dividing it into two ill-defined articular areas. The bone is of about equal transverse dimensions throughout its length.

The proximal phalanx of the fourth digit is short and stout, much narrower than that of the third, but not so depressed. Seen from above it appears somewhat wedge-shaped, the length of the external lateral border greatly exceeds that of the internal. The proximal articular surface is slightly concave and semicircular in outline. The distal end is depressed, with an ill-defined articular surface crossed by a shallow, median vertical groove.

The proximal phalanx of the fifth digit is more massive than that of either the third or fourth, but smaller than the corresponding bones of digits one and two. Seen from above, it presents a broadly wedge-shaped superior surface with an extended external lateral margin, while the inner margin is reduced to a sharp ridge where the proximal and distal surfaces converge and meet at an acute angle. The bone is broader and less depressed than either of the two elements last described. The proximal articular surface is irregularly quadrangular in outline, the transverse dimension about double the vertical. Distally there is a poorly defined articular surface.

The principal dimensions of the phalanges found with this limb and manus are given in the following table, in which the measurements given in columns 1, 2, 3 and 4 show respectively the greatest length and greatest breadth, and the greatest depth at the proximal and distal extremities of the different bones.

	1.		2.		3.		4.	
	mm.	in.	mm.	in.	mm.	in.	mm.	in.
1st Prox. Phalanx	75	2⅞	105	4⅛	85	3⅜	83	3¼
2d " "	90	3½	138	5⅜	100	4	75	2⅞
3d " "	67	2⅝	130	5⅛	65	2½	23	1¼
4th " "	68	2⅝	109	4¼	66	2⅝	42	1⅝
5th " "	75	2⅞	125	4⅞	70	2¾	52	2
Ungual of 1st digit	205	8⅛	64	2½	125	4⅞		

The Sesamoids.—A small, oblong rounded sesamoid was found in position on the palmar side, lying between the distal end of mc. III. and its proximal phalanx. There is little doubt that digits II. and IV. at least bore similar sesamoids in the same position, while others may have been interposed between some of the phalanges. It is not at all impossible that the small ossicles mentioned by Osborn and Granger as found associated with other elements of the manus of Diplodocus and referred by those authors to the carpus were in reality phalangeal sesamoids, as is evidently the case with the present ossicle. The maximum lateral dimension of this bone is 60 mm., 2⅜ inches, vertical 26 mm., 1 inch; while the fore and aft diameter exactly equals the vertical.

FIG. 13. Superior view of sesamoid, about one-fourth natural size. (No. 563.)

MANUS OF BRONTOSAURUS ENTAXONIC IN STRUCTURE.

From the above description and the accompanying figures it will readily be seen that the manus of Brontosaurus, like the pes, was entaxonic instead of mesaxonic as has been supposed by Osborn. Digits II. and III. doubtless were provided with a full complement of phalanges terminating in large unguals bearing powerful claws. In digits IV. and V. the number of phalanges was doubtless successively more and more diminished and the terminal of each reduced to a functionless rounded ossicle similar to those found in the same positions on digits IV. and V. of the pes in both Brontosaurus and Diplodocus.

Not only were digits I., II. and III. the only ones provided with a full complement of phalanges, but the metacarpals decrease in strength from the first to the fifth. The whole structure and arrangement of the different elements of the metacarpus and phalanges is especially modified so that the principal weight of the body was supported, in the manus as in the pes, by the inner side of the foot.

THE MANUS OF DIPLODOCUS AND MOROSAURUS PROBABLY ENTAXONIC IN STRUCTURE.

Considering the many known similarities in the structure of the skeletons of Brontosaurus and Diplodocus there can be little question that the manus in the latter genus was like the pes entaxonic in structure. This would call for a rearrangement of the phalanges of

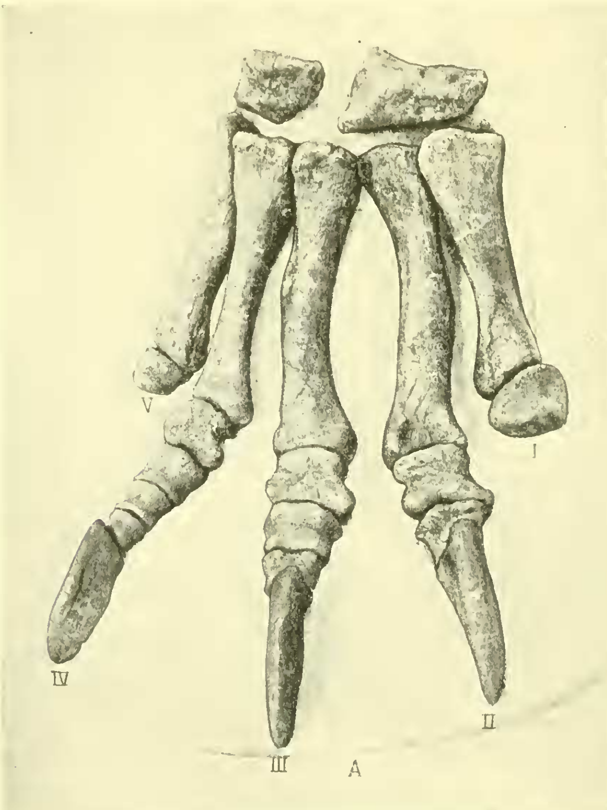

FIG. 14. Right front foot of Morosaurus, one-sixth natural size, after Osborn.

the front feet in the present author's recently published restoration of *Diplodocus carnegii*.[1]

[1] See Mem. of the Carnegie Museum, Vol. I., plate XIII.

I am also strongly inclined to the opinion that the late Professor Marsh was right when in plate XXXVIII. of his Dinosaurs of North America he figured the manus of Morosaurus with digits I., II. and III. provided with claws and IV. and V. deficient in those elements, thus indicating an entaxonic structure of the manus in this genus of sauropod dinosaurs. The Morosaurus manus first described and figured by Osborn,[1] and later associated and figured with a humerus, radius, and ulna by Osborn and Granger does not appear to me as entirely demonstrating the propriety of the arrangement of the phalanges and metacarpals as shown in the figures and described in the text of those authors. A reproduction of Osborn's figure of this foot is given in fig. 14, and I wish especially to call attention to metacarpals II. and III. The curvature of the shafts of these bones as well as the nature of their proximal interarticulation, if their slight contact can be thus designated, is such as to indicate that they pertain to opposite feet. Compare the closely interlocked metacarpals II. and III. shown in figs. 4 and 11 and in plate XX. with the same bones in fig. 14. The arrangement which obtains in the former is well adapted to give the necessary strength and rigidity at that point where it was most needed in the manus of these ponderous beasts, while that of the latter is indicative of weakness and instability at the precise point where stability was to be expected. In short I believe the right foot of Morosaurus as figured by Osborn and Osborn and Granger has the metacarpals and phalanges wrongly placed and that in the figure given by Marsh the arrangement of these elements was essentially correct, although that author may have erred in allowing one or more too many phalanges for digit IV.

SUMMARY.

The chief points regarding the structure of the fore limb and foot of Brontosaurus established in the preceding paragraphs may be summarized as follows:

1. The humerus, radius and ulna are shorter and lighter than the corresponding bones of the hind limbs.

2. The radius and ulna do not cross completely as in the mammalia.

3. The carpus, like the tarsus, consists very likely of a single element—the scapho-lunar.

4. The metacarpals are longer than the metatarsals.

[1] See Bull. Am. Mus. Nat. Hist., Vol. XII., pp. 161–172.

5. The manus, like the pes, is undoubtedly entaxonic in structure in Brontosaurus and very probably so in Diplodocus and Morosaurus.

EXPLANATION OF PLATES.

PLATE XIX.

Palmar view of radius, ulna and manus (No. 563) showing position of bones as they lay imbedded in the matrix. u, ulna; r, radius, x, scapho-lunar; s, sesamoid; metacarpals and phalanges indicated by their respective numerals.

PLATE XX.

Dorsal view of the same. Letters same as above. Both figures a little less than ⅛ natural size.

ARNEGIE MUSEUM, December 28, 1901.